

Optimal Multiple Distributed Generation Output and Placement Based on Line Capacity Increment Index

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Abstract— A lot of Distributed Generation (DG) placement techniques have been in the distribution system. Among those techniques, the DG placement based on power loss (PL) reduction is the most popular methods used by many researchers. However, the selected DG location based on power loss index, sometimes, may cause some of the lines in the system to have higher current flow compared to the initial condition. This new current flow may cause some of the lines to operate in an overloaded condition. Therefore, a new approach to place the DG is proposed in this paper. By using the meta-heuristic optimization technique, which is Ranked Evolutionary Particle Swarm Optimization (REPSO), the DG location and their outputs will give lower power loss as well as minimum line capacity increment (LCI). The 33-bus distribution system is used to perform the proposed technique. The results show that the optimal DG location based on LCI does not only give zero line capacity increment, but also give the lowest power loss value as compared to the other techniques.

Keywords— DG placement, optimization, power loss, line capacity increment

I. INTRODUCTION

Many countries have started to use Distributed Generation (DG) in their power system. With the installation of DG unit, the reliability of the distribution system can be improved [1-4]. Besides that, with the additional of power generation at the demand side, the distribution system can reduce the dependency on transmission/distribution supply. In general, the DG can be divided into two groups, which are dispatchable and non-dispatchable groups. For the dispatchable DG group, such as micro-turbine, cogeneration and mini-hydro, the output of these DGs can be controlled. On the other hand, for the non-dispatchable DG group, the output of the DG is totally depends on input energy, such as wind speed for the Wind Turbine unit and solar irradiation for the PV unit.

Since the dispatchable DG output can be controlled and their input power is not dependent on the energy location (such as wind speed and solar irradiation), many researchers have focused on fully utilizing this DG to improve the distribution network performance. With the DG unit, it can be used to reduce the power loss [5-7], improve the stability of the system [8, 9], minimize the Total Harmonic Distortion (THD) [10, 11], lowering the short circuit level [12, 13] and many more. However, it is very important to have suitable location for the

DG. The incompatibleness of the size and DG location will give an opposite effect to the distribution network. Therefore, many researchers have concentrated to obtain the suitable location and DG output. The meta-heuristic optimization techniques, such as Particle Swarm Optimization (PSO), Bacteria foraging Technique (BFT), Artificial Bee Colony (ABC), are among the most popular approaches that are used to obtain the result.

Garcia *et. al.* are among the latest researchers that worked on optimal DG placement and output in distribution network [14]. They have proposed a new technique, which is called Modified Teaching Learning Based Optimization (MTLBO) algorithm. From the simulation results, the simultaneous optimization for DG output and placement gave higher power loss reduction in the system. On the other hand, an additional action has been taken in the Rosseti *et. al.* work [15]. The authors have integrated the reconfiguration process during the allocation of DG. With the additional reconfiguration process, the power loss in the system can be further reduced. However, the network must have a capability to configure their original condition (with several “normally open switch” lines).

Although the DG can improve the power loss in the system (especially when DG is operated at the optimal value), it is very important to consider the additional cost that might be needed due to the DG installation. Based on our review, no researcher has considered the current changing in the line after the DG installation. Assuming that all the lines in the network have already operated in the maximum capacity (at without DG condition), an additional current flow due to DG connection will cause some lines to be overloaded. Thus, in this study, the change in the current flow will also be considered as one of the optimization objectives, during the process to determine the minimum power loss for distribution network.

The Multi Objective Rank Evolutionary Particle Swarm Optimization (MOREPSO) will be used to determine the placement and the output of DG simultaneously. The problem formulation for the analysis will be described briefly in Section 2. The detail of the algorithm with the Pareto approach will be discussed in Section 3. Section 4 shows the comparison of optimal DG placement and output achieved by MOREPSO with other established papers for 33 bus radial distribution systems. Last but not least, Section 5 presents the conclusion of the study.

II. PROBLEM FORMULATION

The main contribution in this work, compared to other analysis on DG placement, is in terms of consideration on the line current flow after the DG installation. As mentioned in the introduction, if the combination of DG output and location is not suitable, the new current flow in the system might cause the capacity of the line to exceed from their limit. Thus, reinforcement analysis has to be made (either by installing new additional line or etc.) after the DG connection. Besides that, in order to avoid any disturbance to the system performance, several constraints are also being considered. The list of constraints that is used in this analysis is shown below:

a) Active Power DG constraint:

$$P_i^{\min} \leq P_{DG_i} \leq P_i^{\max} \quad (1)$$

All the DG units must operate within their capability limit. In other words, the random value that will be used by MOREPSO should be within the minimum and maximum DG output as shown in (1).

b) Supply-Demand Balance constraint:

$$\sum_{i=1}^k P_{DG} + P_{Substation} = P_{Load} + P_{Losses} \quad (2)$$

In order to ensure that the frequency of the system is not being affected by the DG installation, the total power generated by all DG units and the incoming power from the substation must be equal to the summation of total demand and power loss as shown in (2). With the supply-demand balanced, the frequency of the system will be stable.

c) Voltage Constraint:

$$V_{\min} \leq V_{bus} \leq V_{\max} \quad (3)$$

The voltage value for all buses, after the DG placement and its output, must be maintained at the acceptable limit. In this research, $\pm 5\%$ of voltage variance from the rated value is acceptable. Therefore, if the DG placement caused the voltage in the system to operate beyond this limit, the optimization process will “penalize” the location.

d) Power Injected Constraint:

$$\sum_{i=1}^k P_{DG} < P_{Load} + P_{Losses}, k = \text{no. of DG} \quad (4)$$

The summation of power generated by all DGs must be less than the amount of total demand in the system. This is to avoid any power injection to the grid side.

With all the constraints, the MOREPSO will able to generate a set of feasible solution to be used during the initial analysis and indirectly, it will help the MOREPSO to get the optimal solution. Bear in mind, the same constraints will also be checked every time the updating process is done. The

MOREPSO analysis was conducted using MATLAB programming language in MATLAB 7.8 on a computer powered by a Core2Duo processor, clocked at 2.00GHz and with 2GB RAM.

III. MOREPSO IMPLEMENTATION IN DG PROBLEM

The MOREPSO is formed from the combination between EP concepts in the PSO updating process. In the previous works [16-18], it has shown that the REPSO is capable to give the optimal solution in a faster rate and accurate compared to traditional PSO. The concept of EP has helped the REPSO to filter out the weak solution in every iteration. However, in this work, the REPSO is used to solve the multi-objective optimization problem. Thus, some modification on the REPSO needed to be made, so that it is suitable to be used for analyzing the multi objectives problem. Table I shows the comparison steps between REPSO and MOREPSO algorithms.

The steps in executing MOREPSO are almost similar to REPSO, except for the selection on G_{best} and P_{best} parts and the involvement of EP, which is “ranking” and “selecting” process in the algorithm. From the table, starting from initialization process, a set of initial particles is obtained. The fitness value for these particles is calculated. From these fitness values, the non-dominated particles are selected and stored at external memory or repository. Similar as in PSO or REPSO, the P_{best} for the first iteration is adopted from the initial particles’ position. Next, after the position’s updating process, the concept of EP in REPSO is started. By combining the previous solution set with the current solution set, each particle in the combination set will be compared with other particles. During the comparison process, the number of dominated solution obtained by the particle is recorded. Upon all comparisons are completed, the particles is sorted based on the number of dominated solution – “ranking” process. For example, if the “a” particle dominated all other particles in the combination set, the “a” will have the highest dominated number and will be located at the top position in the ranking process (similar as REPSO – the particles are sorted based on fitness value). Later, N number of particles from the top position is selected as P_{best} .

Thus, in order to implement the DG analysis in the MOREPSO algorithm, the “particle position”, x_i is set to:

$$x_i = [DG_{location-1} \quad DG_{location-n}, DG_{output-1} \quad DG_{output-n}] \quad (5)$$

The objective functions that are used to determine the best DG position and output are:

a) Total Power Loss

$$P_{losses} = \sum_{i=1}^n |I_{ai}|^2 R_i \quad (6)$$

where,

i = Number of lines in the system.

I_{ai} = Line real active current.

R_i = Line resistance.

b) *Line Capacity Increment (LCI) index*

$$LCI_i = \frac{I_{new(with\ DG)-i} - I_{initial_i}}{I_{initial_i}} \times 100\% \quad (7)$$

The LCI index is used to show the condition of the line after the DG installation. If the new current flow (after DG installation) is lower than the initial line flow (before DG installation), the LCI value is set to zero. Otherwise, the LCI value is calculated based on (7).

TABLE I. THE COMPARISON BETWEEN REPSO AND MOREPSO ALGORITHM

Step	REPSO	MOREPSO
1	Initialized the particle position, xi	Initialized the particle position, xi
2	Calculate the Fitness value for each position	Calculate the Multiple Fitness values for each position
3	Set the P_{best} = initial position G_{best} = the best position in current iteration	Set the P_{best} = initial position G_{best} = obtain from repository set (Non-dominated point)
4	Calculate the velocity (v_i) and the updating position, ($x_{i(new)}$)	Calculate the velocity (v_i) and the updating position, ($x_{i(new)}$)
5	Calculate the Fitness for new particles	Calculate the Fitness for new particles
6	Determine the P_{best} Combine the previous population (xi) with the new population ($x_{i(new)}$) Sort the combination population based on Fitness value (Highest to lowest) Select the top N particles as P_{best}	Determine the P_{best} Combine the previous population (X) with the new population (X^{new}) for $i=1:2*N$ Determine the number of particles that is dominated by “ i ” in the combination set end Sort the population based on “ <i>dominated</i> ” value (Highest to lowest) Select the top N particles as P_{best}
7	Set the top position in the Pbest process (combination – after filter) as the Gbest.	Determine the G_{best} from repository set
8	Check the stopping criteria if Yes Stop else Repeat Step 4	Check the stopping criteria if Yes Stop else Repeat Step 4

IV. RESULT & DISCUSSIONS

Fig. 1 shows the 33-bus distribution used in this analysis. The line data and bus data of the system is shown in the Appendices A and B respectively. The base voltage that is used in the analysis is 12.66kV and the base power is 10MW [19]. All the DG units that are placed in the system are operated at unity power factor.

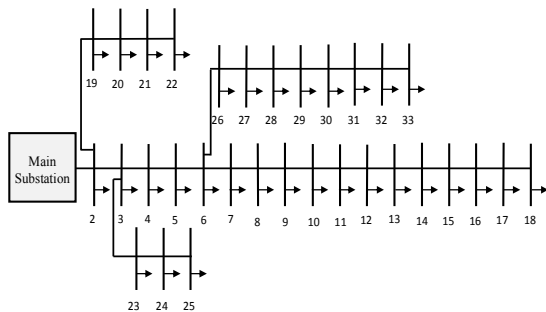


Fig. 1. The case study network: 33-bus radial distribution system

Table II shows the optimal DG location and output that is given by MOREPSO in the 33-bus distribution system. By comparing the results with the other 2 research works ([20] and [21]), the MOREPSO is capable to give suitable location and output for DG units, in order to further improved the system performance.

From the result, the placement of DG at buses 14, 24 and 31 given by MOREPSO has helped the system to have the lowest power loss value. The power loss given by MOREPSO is 71.55kW, which is 64.02% lower than method in [20] and 9.02% lower than method in [21]. Besides that, methods [20] and [21] have also caused some of the lines in the system to operate at higher current flow, as compared to initial condition (indicated by LCI value). On the other hand, the MOREPSO give 0% of LCI value to the system. In other words, there is no line in the system that has higher current flow after the DG installation.

TABLE II. THE COMPARISON BETWEEN REPSO AND MOREPSO ALGORITHM

Method for DG placement	DG Location (bus)	DG Output (MW)	Power Loss (kW)	LCI _{total} (%)
33-bus distribution system Without DG: Power Loss = 203.18kW				
Power Loss Index [20]	DG ₁ = 30 DG ₂ = 31 DG ₃ = 32	DG ₁ = 1.1138 DG ₂ = 0.1503 DG ₃ = 0.2701	117.3558	13.12% (Line 29-30)
Maximum Power Loss Saving [21]	DG ₁ = 6 DG ₂ = 14 DG ₃ = 31	DG ₁ = 1.6667 DG ₂ = 0.7361 DG ₃ = 0.8904	78	1.82% (Line 30-31)
MOREPSO with LCI Index	DG ₁ = 14 DG ₂ = 24 DG ₃ = 30	DG ₁ = 0.7542 DG ₂ = 1.0994 DG ₃ = 1.0714	71.5487	0%

Fig. 2 shows the difference in current magnitude flow in all lines, after the placement of DG via MOREPSO with LCI technique. It is proven that all lines in the system is lower than the initial condition when the DG is located at buses 14, 24 and 30 with the optimal output of 0.7542 MW, 1.0994 MW and 1.0714 MW respectively.

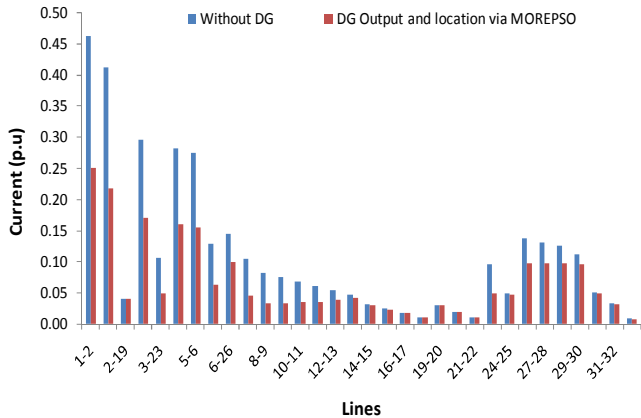


Fig. 2. The different in the current flow after the DG allocation via MOREPSO

In terms of voltage profile, the MOREPSO and method in [20] are able to fulfil the voltage constraint limit as shown in Figure 3. All buses in the system operated between 0.95p.u to 1.05p.u. Although the placement and the output of DG using the method in [21] has improved the voltage profile of distribution network (compared to without DG case), there are still some buses operating at the voltage level lower than the acceptable limit. Therefore, this proved that the location and the output of DG give a significant influence to the voltage profile of the system. Even though the MOREPSO did not give the best voltage profile, it still obeys and fulfils the voltage limit of the system and reduces the power loss to the lowest value.

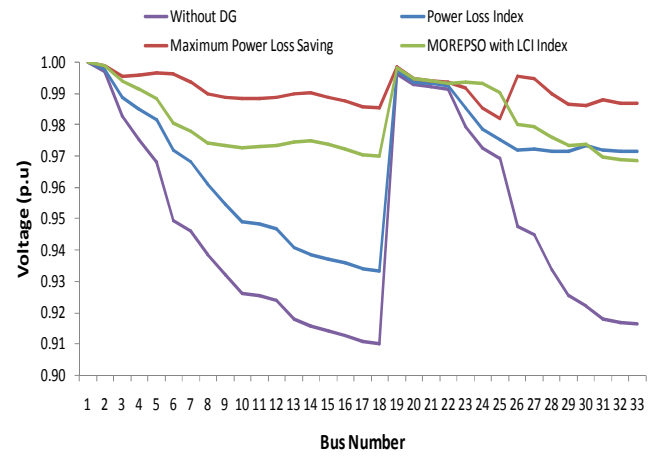


Fig. 3. The different voltage profile due to DG location and output

Since MOREPSO is based on meta-heuristic optimization, the efficiency and the effectiveness of the algorithm should be measured by the consistency in giving similar results in several trials. Figure 4 shows the power loss results given by MOREPSO in 10 trials, after the optimal placement has been achieved. It can be clearly seen that the differences between the power loss results given by MOREPSO is very small. The standard deviation for the MOREPSO is only 2.4×10^{-11} . In other words, the MOREPSO is capable to give similar power output for each DG unit during the optimization analysis.

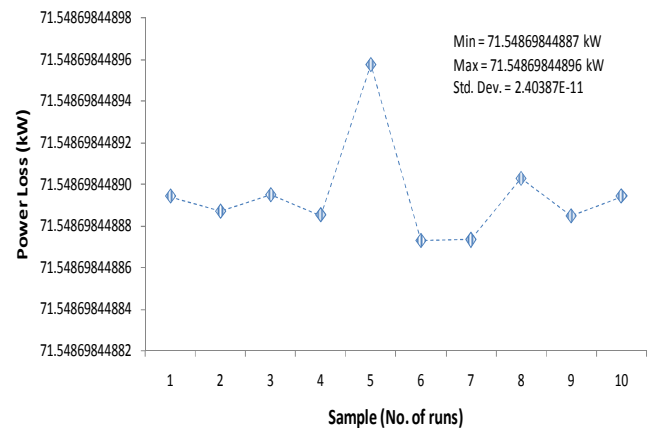


Fig. 4. The performance of MOREPSO to determine optimal DG output

Unlike in some multi-objective optimization problems, the use of MOREPSO in solving the DG placement and output based on power loss and LCI value produces only single optimal solution (1 Pareto point). Figure 5 shows all the dominated points in the Pareto analysis for this problem. Although some solutions give 0% of LCI, the total power loss value is higher than 71.5487 kW. Therefore, the 71.5487 kW of power loss with the 0% of LCI has dominated all these solutions and become a single solution for the DG placement and output problem.

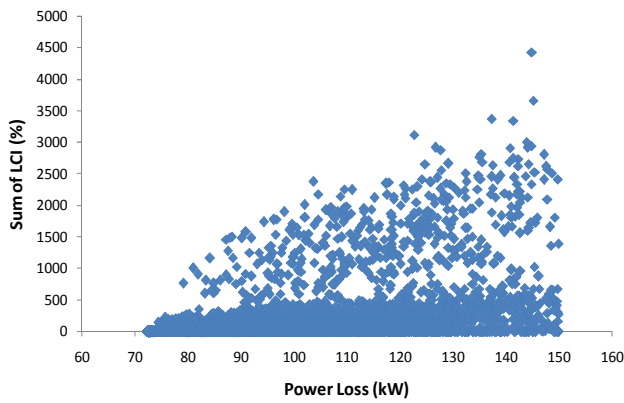


Fig. 5. The Non-Dominated points given by MOREPSO in determine optimal DG output and placement

V. RESULT & DISCUSSIONS

The use of Multi-Objective Ranked Evolutionary Particle Swarm Optimization in solving the DG placement and optimal output does not only provide lower power loss to the distribution network, but it also gives lower current flow in all lines after the DG installation. It means that, there is no additional action or cost need to be added after the DG installation. Besides that, the voltage profile in the system is also improved to the allowable limit. With the consistent results given by MOREPSO in 10 trials analysis, it can be concluded that the MOREPSO can be used as an alternative approach to determine the suitable location and output of multiple DG units in any system.

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APPENDICES

APPENDIX A – LINE DATA

Sending	Receiving	R (ohm)	X (ohm)
1	2	0.0922	0.0477
2	3	0.4930	0.2511
3	4	0.3660	0.1864
4	5	0.3811	0.1941
5	6	0.8190	0.7070
6	7	0.1872	0.6188
7	8	0.7114	1.2351
8	9	1.0300	0.7400
9	10	1.0400	0.7400
10	11	0.1966	0.0650
11	12	0.3744	0.1238
12	13	1.4680	1.1550
13	14	0.5416	0.7129
14	15	0.5910	0.5260
15	16	0.7463	0.5450
16	17	1.2890	1.7210
17	18	0.7320	0.5740
2	19	0.1640	0.1565
19	20	1.5042	1.3554

20	21	0.4095	0.4784
21	22	0.7089	0.9373
3	23	0.4512	0.3083
23	24	0.8980	0.7091
24	25	0.8960	0.7011
6	26	0.2030	0.1034
26	27	0.2842	0.1447
27	28	1.059	0.9337
28	29	0.8042	0.7006
29	30	0.5075	0.2585
30	31	0.9744	0.963
31	32	0.3105	0.3619
32	33	0.341	0.5302

APPENDIX B – BUS DATA

Bus	P-Load (MW)	Q-Load (MW)	P-Gen (MW)	Q-Gen (MW)
2	0.100	0.060	0.000	0.000
3	0.090	0.040	0.000	0.000
4	0.120	0.080	0.000	0.000
5	0.060	0.030	0.000	0.000
6	0.060	0.020	0.000	0.000
7	0.200	0.100	0.000	0.000
8	0.200	0.100	0.000	0.000
9	0.060	0.020	0.000	0.000
10	0.060	0.020	0.000	0.000
11	0.045	0.030	0.000	0.000
12	0.060	0.035	0.000	0.000
13	0.060	0.035	0.000	0.000
14	0.120	0.080	0.000	0.000
15	0.060	0.010	0.000	0.000
16	0.060	0.020	0.000	0.000
17	0.060	0.020	0.000	0.000
18	0.090	0.040	0.000	0.000
19	0.090	0.040	0.000	0.000
20	0.090	0.040	0.000	0.000
21	0.090	0.040	0.000	0.000
22	0.090	0.040	0.000	0.000
23	0.090	0.050	0.000	0.000
24	0.420	0.200	0.000	0.000
25	0.420	0.200	0.000	0.000
26	0.060	0.025	0.000	0.000
27	0.060	0.025	0.000	0.000
28	0.060	0.020	0.000	0.000
29	0.120	0.070	0.000	0.000
30	0.200	0.600	0.000	0.000
31	0.150	0.070	0.000	0.000
32	0.210	0.100	0.000	0.000
33	0.060	0.040	0.000	0.000

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